Draft

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

A FOCUSED REVIEW OF THE SEC PETITION AND NIOSH EVALUATION REPORT FOR UNITED NUCLEAR CORPORATION, PETITION SEC-00116

Contract No. 200-2009-28555
SCA-TR-SEC2010-0017

Prepared by

J. Mauro
R. Leggett
N. Briggs
J. Porrovecchio
S. Cohen & Associates
1608 Spring Hill Road, Suite 400
Vienna, VA 22182

September 2010

S. COHEN & ASSOCIATES: ***Technical Support for the Advisory Board on Radiation & Worker Health Review of NIOSH Dose Reconstruction Program***	Document No. SCA-TR-SEC2010-0017 Effective Date: Draft – September 30, 2010 Revision No. 0 (Draft)
A FOCUSED REVIEW OF THE SEC PETITION AND NIOSH EVALUATION REPORT FOR UNITED NUCLEAR CORPORATION, PETITION SEC-00116	Page 2 of 37
Task Manager: ________________________________ Date:____________ John Mauro, PhD, CHP	Supersedes: N/A
Project Manager: ________________________________ Date:____________ John Mauro, PhD, CHP	Peer Reviewers: U. Hans Behling Robert Anigstein

Record of Revisions

Revision Number	Effective Date	Description of Revision
0 (Draft)	09/29/2010	Initial issue

TABLE OF CONTENTS

ABBREVIATIONS AND ACRONYMS

Advisory Board	Advisory Board on Radiation and Worker Health
AEC	Atomic Energy Commission
ALARA	As low as reasonably achievable
AWE	Atomic Weapons Employer
BE	beryllium
CATI	Computer-Assisted Telephone Interview
CFR	*Code of Federal Regulations*
Ci	curies
cm	centimeter
DOE	U.S. Department of Energy
dpm	disintegrations per minute
EEOICPA	Energy Employees Occupational Illness Compensation Program Act of 2000
g/cm^3	grams per cubic centimeter
GM	Geometric mean
HEU	Highly enriched uranium
ICRP	International Commission on Radiological Protection
kg	kilogram
L	liter
LOD	limit of detection
m^3	cubic meter
MAC	Maximum allowable concentration
MCNP	Monte Carlo N-Particle (computer code)
mL	milliliter
mr	milliRoentgen
mrad	millirad
mrem	millirem
mrep	millirep
NIOSH	National Institute for Occupational Safety and Health
NOCTS	NIOSH OCAS Claims Tracking System
$n\ s^{-1}$	neutrons per second
ORAUT	Oak Ridge Associated Universities Team

ORO	Oak Ridge Operations
OTIB	ORAUT Technical Information Bulletin
PAS	personal air sampling
pCi	picocuries
pdf	portable document format
PPE	personnel protective equipment
SC&A	S. Cohen and Associates (SC&A, Inc.)
SEC	Special Exposure Cohort
SRDB	Site Research Database
TBD	Technical Basis Document
Th	thorium
ThO_2	thorium dioxide
U	uranium
UF_4	uranium tetrafluoride
UF_6	uranium hexafluoride
UO_2	uranium dioxide
UNC	United Nuclear Corporation
μCi	microcurie

1.0 BACKGROUND AND STATEMENT OF PURPOSE

In September of 2009, S. Cohen and Associates (SC&A, Inc.) submitted a draft review of the *Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium – Appendix D: United Nuclear Corp.*, Revision 0 (Allen 2008), to the Advisory Board on Radiation and Worker Health (Advisory Board) and NIOSH for discussion/resolution of six findings identified by SC&A (SC&A 2009). However, the Advisory Board's Work Group on TBD-6000/6001 elected to postpone any discussion/resolution of the findings on behalf of Revision 0, due to forthcoming changes NIOSH planned to introduce in Revision 1 of Appendix D. This revision (Allen 2010) was issued on April 30, 2010.

In response to NIOSH's revision, SC&A was tasked to evaluate Appendix D, **Revision 1**, and assess whether findings previously identified for Revision 0 have been adequately addressed. That report, titled *A Critical Review of Revision 1 of the NIOSH Site Profile for the United Nuclear Corporation, Missouri, Addendum to SCA-TR-SP2009-004* (SC&A 2010), was delivered to NIOSH and the Board on June 24, 2010. The purpose of that report was to serve as an addendum to SC&A's evaluation of Allen 2008. SC&A had originally identified six findings in our review of Allen 2008, as follows:

- Finding 1 concerned the methods used to reconstruct medical doses. Our review of Revision 1 of Appendix D (Allen 2010) found that this issue has not been resolved.

- Finding 2 concerned the very limited information NIOSH used as the basis to reconstruct external doses. Our review of Revision 1 found that this finding may have been adequately addressed, pending SC&A's review of the new dosimetry data that NIOSH employed in revising external whole-body and skin doses.

- Finding 3 concerned the lack of guidance for reconstructing neutron doses. Our review of Revision 1 determined that this finding has been partially addressed, in that NIOSH presented a bounding model for assigning neutron doses. A further discussion of this issue is presented in Section 4.2 of this report.

- Finding 4 concerned conflicting statements regarding how internal dose was to be derived (i.e., it was not clear whether air sampling or bioassay data were to be used), and also what appeared to be the use of dose reconstruction procedures that significantly under-estimated internal doses. Our review of Revision 1 determined that this finding has been partially addressed, but further discussions may be required to justify NIOSH's recommended use of the geometric mean for the coworker model.

- Finding 5 concerned insufficient information regarding methods that will be used to reconstruct doses to workers during the residual period. Our review of Revision 1 determined that this finding was not addressed/resolved.

- Finding 6 concerned insufficient information that would allow the validation of default external doses estimates during the residual period. Our review of Revision 1 determined that this finding was not addressed/resolved.

A meeting of the newly constituted TBD-6001 Work Group was held on July 7, 2010. One of the topics addressed at that meeting was SC&A's findings regarding Revision 1 to Appendix D, which will hereafter be referred to as simply "Appendix D." At the meeting, Hans Behling, principal author of SC&A's review of Appendix D, summarized his findings. One of the important questions that was posed to SC&A during the meeting was whether we believed that any of the issues raised by SC&A rise to the level of a Special Exposure Cohort (SEC) issue. This became an important question, because on January 28, 2010, NIOSH issued its evaluation report for SEC Petition-00116 dealing with United Nuclear Corporation (NIOSH 2010). SC&A was not explicitly tasked to review the petition or the evaluation report; however, we were asked to give our initial impressions regarding possible SEC issues as part of our review of Appendix D. Dr. Behling responded to this question by stating that there appeared to be a considerable amount of film badge and bioassay data that could be used to reconstruct external and internal doses and to develop coworker models. However, as indicated in the findings of our review of Appendix D, we would like to look more closely at the possible issues related to data completeness and data adequacy before we offer an SC&A position regarding whether SEC issues remain that might need to be addressed.

During the work group meeting, Dr. Mauro recommended that SC&A prepare a statement of work for a focused review of the SEC petition and evaluation report. That report could be used by the work group to help judge whether to recommend to the Advisory Board that NIOSH's recommendations regarding the petition be approved or to withhold a recommendation until certain issues are resolved.

On July 13, 2010, Dr. Mauro transmitted the following recommendations for a focused review of Findings 2, 3, and 4, identified in our review of Appendix D:

> Finding 2 – Download the new external dosimetry data, load the data into a database, and check if the data are of sufficient quality and are adequate to build a coworker model that can be used for different time periods, operations, and job categories.
>
> Finding 3 – Confirm that neutron exposure data are adequate for building a coworker model.
>
> Finding 4 – Conduct a more detailed investigation of the internal dosimetry data to ensure adequacy for use in building a coworker model

On July 13, 2010, SC&A received an e-mail from Henry Anderson, Chairman of the TBD-6001 Work Group, directing us to proceed with the recommended work. This report presents the results of SC&A's investigations pertaining to this matter. The report is organized into six sections. Following this introduction, Section 2 briefly describes the Atomic Weapons Employer (AWE) activities that took place at United Nuclear. Section 3 presents a summary of the issues identified in the petition, and the degree to which the evaluation report and Appendix D address these issues. Section 4 presents our focused review of external dosimetry issues, and Section 5 presents our focused review of internal dosimetry issues. Section 6 presents a summary of our findings regarding this matter, along with a discussion of the concerns raised by the petitioner.

Please note that, at the time of the preparation of this report, a site visit and interviews of workers, claimants, and petitioners had not yet been performed. This report will be amended upon completion of that work.

2.0 DESCRIPTION OF UNC-HEMATITE FACILITIES AND OPERATIONS

The production facilities at the United Nuclear Corporation (UNC)-Hematite site consisted of two main buildings, each with several thousand square feet of floor space. An incoming storage and blending building and an outgoing storage building were located between the two main buildings.

The main function of the UNC-Hematite plant was production of uranium metal and uranium compounds from natural and enriched uranium feed stocks for use as fuel in nuclear reactors, including the U.S. Navy's submarine reactors. Starting in 1959, the facility processed un-irradiated uranium scrap for the recovery of enriched uranium for use in the Atomic Energy Commission's (AEC's) nuclear weapons complex.

Operations at UNC-Hematite included conversion of uranium hexafluoride (UF_6) to uranium dioxide (UO_2) powder, which was pressed into pellets and furnace-fired into a ceramic form suitable for loading into fuel assemblies. Chemical conversions of UF_6 to uranium carbide and uranium metal and various research and development projects were also conducted. In general, an increase in U-235 enrichment was associated with work conducted in the Green Room (low enrichment, about 2%–5% U-235), Blue Room (intermediate enrichment, about 5%–20% U-235), and Red Room (high enrichment, greater than about 20% U-235). The Blender Room was used for both low and intermediate enrichment operations. Work in the Item Plant at Hematite was often classified and likely involved highly enriched uranium.

Approximately 9 tons of natural thorium was on site for a specific project conducted in 1964. Thorium dioxide (ThO_2) powder was mixed with UO_2 powder to produce Th-U fuel pellets for use in fuel assemblies for breeder reactors. Each pellet consisted of a blend of 97% ThO_2 and 3% UO_2 (U-235 enrichment of about 93%) that had been compressed and heated in a furnace. Operational and monitoring data indicate that thorium exposures from the 1964 operations and cleanup of residual thorium dioxide posed a potential internal hazard to workers.

3.0 SUMMARY OF ISSUES RAISED IN SEC PETITON-00116

Before proceeding with a focused review of external and internal dosimetry issues in Appendix D and in the evaluation report, this section presents a summary of the concerns raised in the petition. SC&A carefully reviewed the petition and condensed the petition into the following six concerns:[1]

Concern #1. Transuranics are not included in the site profile for Hematite Site operations and dose reconstruction (Appendix D). This is a significant finding that should be considered. Indications that recycled uranium may have been brought to the Hematite Site for salvage or research were likewise not addressed in the site profile.

Concern #2. The dose reconstruction protocols and the dosimetry data upon which the protocols depend, as delineated in the site profile, may not be consistent with actual occupations and task assignments at the Hematite facility, the source term (inclusive of transuranics), the extent of residual contamination, the extent of bioassay data applied to claimants, personal protective equipment, and housekeeping practices.

Concern #3. While there are indications that Geiger counter scans were used to monitor workers leaving contaminated areas, and that at times clothing was replaced if found to be contaminated, accepted as low as reasonably achievable (ALARA) protocols were not always implemented at the site. Specifically, the lack of adequate decontamination of personnel leaving the site could have resulted in the contamination of workers' homes, resulting in internal and external exposures of workers and their families. [**Redacted**].

Concern #4. Internal and external dose reconstructions are challenged by petitioners' recollections of bioassay results not being shared, lack of testing, lack of annual medical exams (including blood tests), lack of confidence in personal dosimetry badge results, and both acute (incidents) and chronic (allegation of negligence) exposure to contaminants. Worker job categories and exposure assumptions may not be consistent with duties performed by workers. For example, security guards performed laboratory technician work. Also, inadequately trained and monitored security guards responded to incidents.

Concern #5. Actual conditions/incidents at the site may have a bearing on the appropriateness of site profile assumptions. For example, petitioners reported incidents with possible acute exposures, and possible criticality incidents.

Concern #6. The site profile should specifically address other petitioner comments and allegations. These allegations deal with falsification of data, fundamental disregard for human life, lack of quality control, lack of dissemination of important information, and secondary exposure (i.e., exposures of family members) to contamination.

[1] The actual petition is over 90 pages and we did our best to briefly summarize the salient concerns raised by the petition. We welcome feedback from the petitioners regarding the degree to which we captured their concerns in this very abbreviated summary.

A more detailed accounting of the issues raised in the petition is provided in Attachment A.

We would like to point out that the evaluation report does not specifically address the individual concerns raised by the petitioners. In the sections that follow, we try to assess the degree to which these concerns have a direct bearing on the ability of NIOSH to perform internal and external dose reconstructions that are scientifically sound and claimant favorable.

4.0 FOCUSED REVIEW OF EXTERNAL DOSIMETRY DATA AND EXTERNAL DOSIMETRY PROTOCOLS FOR WORKERS AT UNITED NUCLEAR CORPORATION

4.1 EXTERNAL GAMMA AND BETA DOSIMETRY

Following the publication of Revision 1 to Appendix D, SC&A issued an addendum to its original site profile review on June 17, 2010 (SC&A 2010). In that addendum, SC&A explains that the use of film badge data adequately addresses the concerns of Finding 2. However, SC&A states that we "intend to request access to these data and upon our review, will provide the work group with a final opinion regarding Finding 2." In addition, the work group authorized SC&A to perform a focused review of the external dosimetry data with regard to data adequacy and completeness required as part of a review of an SEC petition and evaluation report. In accordance with the direction of the work group, SC&A further reviewed Appendix D, the NIOSH SEC Petition Evaluation Report for SEC-00116 (NIOSH 2010), and all of the available external monitoring documents for personnel at UNC, which include the following:

- External Exposure Reports 1963. External Radiation Exposure Reports for various months in 1963. United Nuclear Corp. SRDB Ref ID 62274.
- External Exposure Reports 1964. External Radiation Exposure Reports for various months in 1964. United Nuclear Corp. SRDB Ref ID 62272.
- External Exposure Reports 1965. External Radiation Exposure Reports for various months in 1965. United Nuclear Corp. SRDB Ref ID 62271.
- Tabulation Sheet 1966. Tabulation Sheet – Dosimetry Records, Year 1966. United Nuclear Corp. SRDB Ref ID 62180.
- Tabulation Sheet 1967. Tabulation Sheet – Dosimetry Records, Year 1967. United Nuclear Corp. SRDB Ref ID 62267.
- Tabulation Sheet 1968. Tabulation Sheet – Dosimetry Records, Year 1968. United Nuclear Corp. SRDB Ref ID 62187.
- Tabulation Sheet 1969. Tabulation Sheet – Dosimetry Records, Year 1969. United Nuclear Corp. SRDB Ref ID 62266.
- Tabulation Sheet 1970. Tabulation Sheet – Dosimetry Records, Year 1970. United Nuclear Corp. SRDB Ref ID 62231.
- Tabulation Sheet 1971. Tabulation Sheet – Dosimetry Records, Year 1971. United Nuclear Corp. SRDB Ref ID 62229.

- Tabulation Sheet 1972. Tabulation Sheet – Dosimetry Records, Year 1972. United Nuclear Corp. SRDB Ref ID 62227.

- Tabulation Sheet 1973. Tabulation Sheet – Dosimetry Records, Year 1973. United Nuclear Corp. SRDB Ref ID 62225.

- AEC Compliance Inspection Report 1958. U.S. Atomic Energy Commission. SRDB Ref ID 3822, p. 14.

- AEC Compliance Inspection Report 1960. U.S. Atomic Energy Commission. SRDB Ref ID 3944, pages 45–59.

- AEC Compliance Inspection Report 1960. U.S. Atomic Energy Commission. SRDB Ref ID 7145, pages 44–58

- AEC Compliance Inspection Report 1961. U.S. Atomic Energy. SRDB Ref ID 56196.

SC&A reviewed each of these documents and compiled all of the available film badge data into an Excel spreadsheet, presented in its entirety in Attachment C, and summarized here in Table 1. We were able to verify all of the statements made by NIOSH in Appendix D of TBD-6001 and the evaluation report regarding the UNC film badge records. From an SEC perspective, we reviewed the external dosimetry data, as reproduced and reorganized in Attachment C, for data completeness and data adequacy. Specifically, we investigated the degree to which sufficient data are available to reconstruct the external doses to workers and/or develop external dosimetry coworker models for all workers for the time periods of concern by job category and job location. For those time periods, job categories, and or job locations where there are limited or no external dosimetry data, we investigated whether plausible upper-bound external doses could be assigned to those workers using the existing data.

The film badge results are presented in various forms throughout the period of 1958 through 1973. Therefore, NIOSH developed different approaches for the UNC coworker model for each year of the operational period, as presented in Tables D.2 and D.3 of Appendix D. These methods are described below, along with the data descriptions. Individual measurements are not available for the years 1958 through 1960, but various compliance inspection reports summarize the personnel doses for those years.

Table 1. Summary of Film Badge Results for UNC Personnel 1961–1973

Year	No. of Monitored Workers	Range of Average Exposures (rem/week)			
		Gamma		Beta	
1961	45	0-0.035		0-0.675	
1962	98	0-0.28		0-1.74	
1963	38	0.01-0.28		0-1.3	
1964	29	0-0.16		0-0.85	
1965	16	0-0.14		0-0.36	
		Cumulative beta-gamma annual exposure (rem)			
		Min	**Max**	**Median**	**Average**
1966	139	0	6.35	0.15	0.44
1967	127	0	1.61	0.12	0.22
1968	176	0	5.98	0.13	0.36
1969	186	0	3.12	0.13	0.39
1970	213	0	4.91	0.19	0.38
1971	64	0	0.67	0.02	0.09
1972	93	0	2.57	0.06	0.19
1973	64	0	6.64	0.04	0.43

<u>1958</u>

The following is the summary of the doses received by personnel during the year 1958:

> *Permanent operating personnel at Hematite plant are monitored on a weekly basis while rotating personnel are monitoring monthly. Complete individual exposure records and summaries are maintained on all employees and were reviewed. The average exposure of Hematite plant personnel during the past year, as indicated by the records, was 80 mrad due to beta radiation and 36 mrad due to gamma radiation. The maximum single six months accumulative exposure recorded as due to beta was 2525 mrad while the maximum due to gamma was 380 mrad. No single weekly exposure in excess of the permissible weekly exposure was noted.* (AEC Compliance Inspection Report 1958, p.14)

NIOSH assigned coworker beta and gamma doses for the year 1958 using the following method:

> *A yearly missed dose based on 20 mr (LOD/2) per week was added to the average values to derive a geometric mean (GM) for both the beta dose and the gamma dose. The yearly missed dose was also added to the maximum values (adjusted to an annual dose) to produce values at the 95th percentile.* (Allen 2010)

SC&A found the method used to assign coworker dose for the year 1958 to be scientifically sound. The inclusion of weekly missed dose in the model is a claimant-favorable approach.

<u>1959</u>

The following is the summary of the doses received by personnel during the year 1959:

> *Records for the current monthly program show an average weekly exposure, monthly and quarterly cumulative exposures. The weekly records show exposures to 100 mrep β and the monthly record shows exposures to 240 mrem β with averages of 80–90 mrep. Gamma readings to 15 mrem for the monthly program are also recorded. The above quoted exposures are all for operations personnel while the recorded exposures for pilot plant, laboratory and maintenance personnel have all been less. The records reflect no personnel exposures that have exceeded the permissible limits of 10 CFR 20.* (SRDB 7145, p.50)

NIOSH assigned coworker beta and gamma doses for the year 1959 using the following method:

> *Since it is not clear when in 1959 the exchange frequency changed, missed dose was assigned based on a weekly exchange frequency for the entire year. Missed dose was added to the maximum recorded values and used to represent the 95th percentile dose. Missed dose was added to the average beta dose and used to represent the GM beta dose. The GM gamma dose was assigned based on the GM beta dose adjusted using the average beta to gamma ratio between 1961 and 1965.* (Allen 2010)

As with the assigned doses for 1958, SC&A found the inclusion of missed dose to be scientifically sound and claimant favorable. However, SC&A does have a concern regarding the use and calculation of beta-gamma ratios.

Finding 1. There is a need for better documentation of the beta-gamma ratios used to reconstruct external doses.

NIOSH states that the gamma doses were calculated based on beta-gamma ratios developed from the data from 1961–1965. In order to develop these ratios, the values that were below the LOD/2 should not have been included in the calculation. Since these ratios were not published in Appendix D of TBD-6001, it is not clear how they were calculated. In addition, NIOSH should have presented a correlation coefficient between the beta and gamma values in order to demonstrate that there is a robust and consistent relationship between the beta and gamma measurements observed at UNC.

<u>1960</u>

The following is the summary of the doses received by personnel during 1960:

> *Records of film readings for 1960 show no exposures greater than the 10 CFR 20 limits prior to January 1, 1961, with some few readings up to 100 mrem/wk but the majority of the readings were near the threshold of the film or no greater than 50 mrem/wk.* (AEC Compliance Inspection Report 1961, p.13)

NIOSH used the same method for the assignment of coworker doses for the year 1960 as for the year 1959. There is no mention of the addition of missed dose, but the values in Table D.2 are comparable to those for 1959. We therefore find favorably for 1960, but like 1959, we have concerns regarding the bases and claimant favorability of the beta/gamma ratios used to derive the doses.

<u>1961–1973</u>

Starting with the year 1961, the individual film badge records for each worker are documented and available. For the years 1961 and 1962, the monthly data are presented as average weekly beta and gamma exposures in units of either mrep per week or rem per week. The cumulative quarterly totals are also given for each worker for each month of 1961 and 1962. For the years 1963 through 1965, the external monitoring data are presented as monthly exposures to beta and gamma in units of rem per month. The cumulative quarterly totals are also presented for each worker for these years. For the years 1966 through the end of the operational period in 1973, the film badge records are presented as an annual combined beta-gamma exposure for each worker.

For 1961 through 1965, when separate beta and gamma values are available, NIOSH used those data to develop GM and 95th percentile doses. For the years 1966 through 1973, when only the annual combined beta-gamma doses are available, NIOSH used the beta-gamma dose ratios:

> *Using the 1961 through 1965 data, a ratio of beta to gamma was calculated for each of those years, and the average of that ratio was applied to the 1966 through 1973 data to derive annual beta and gamma dose at the GM and the 95th percentile.* (Allen 2010)

Finding 2. How were the beta-gamma ratios derived, and how will they be used in a claimant-favorable way for reconstructing external doses for 1961 through 1965?

SC&A has a finding regarding the use of the data for the period 1961 through 1965. It is not clear from the procedures in Appendix D if the values below the LOD/2 are included in the model. In order to develop a claimant-favorable model, all values below the LOD/2 should be adjusted to the LOD/2, which in this case would be 20 mrem. For the 1966 through 1973 time period, SC&A has the same concern regarding the derivation of the beta-gamma dose ratios. It is not clear if the values below the LOD/2 were included in the model, and a correlation coefficient has not been presented demonstrating the relationship between the beta and gamma exposures at UNC.

SC&A also reviewed the UNC external monitoring data from the point of view of data adequacy. We wanted to determine if the film badge data used to develop the external coworker model described in Appendix D adequately represents all work locations and all job functions performed during the operational period at UNC. Section 5.2.2.1 of the SEC evaluation report (NIOSH 2010) indicates that the potential for external radiation exposure existed “primarily from operations in the Red Room, Blue Room, Green Room, and Item Plant” related to uranium enrichment processes. The information contained in the AEC Compliance Inspection Report for 1960 (p. 50) indicates that the highest recorded external exposures were received by the operations personnel, and the workers involved in the pilot plant, the laboratory, and maintenance had lower recorded external exposures. In the existing UNC coworker model (Allen 2010, Tables D.2 and D.3), NIOSH recommends that the operators should be assigned the

95th percentile doses from the coworker model, while other workers should be assigned the GM values from the model. SC&A agrees with the assumption that the highest potential for external exposure existed for operators involved in uranium enrichment processes, particularly in the Red Room, Blue Room, Green Room, and Item Plants, and that the assignment of the 95th percentile doses for the operators is claimant favorable. However, does the film badge data used in the development of the coworker model adequately represent the individuals and work locations with the highest potential for exposure?

In order to determine the adequacy of the data for the model, SC&A extracted all of the UNC claimants from the NOCTS database. Since we could determine the job titles and work locations for each of the monitored workers listed in the original film badge records referenced by NIOSH in the evaluation report, we decided to perform a search of the NOCTS database and review the Computer-Assisted Telephone Interview (CATI) reports and Department of Energy (DOE) records for those individuals. For each of the workers, SC&A listed their employment period, job titles, work locations, and whether or not they had available film badge records during the operational period, all of which is presented in Attachment B and summarized below in Table 2. Of the 54 claimants, 47 of them worked at UNC during the operational period. Of these 47 claimants, [**redacted**] appeared to only have worked at the Mallinckrodt Destrehan Street facility, instead of the Hematite facility. Finally, SC&A determined that 15 of the UNC claimants are described as some type of operator that has available film badge data referenced by NIOSH in their evaluation report and reviewed by SC&A. Attachment B also shows that most of the 27 Hematite claimants with film badge records worked in all areas of the facility, particularly the uranium enrichment rooms, and therefore the data do represent a cross section of the entire facility, including those rooms with the potential for the highest exposure.

Table 2. Summary of Review of UNC Claimants from NOCTS Database

Total # of UNC claimants	# of claimants from operational period	# of claimants from Hematite facility	# of claimants from Hematite facility with film badge records reviewed by SC&A	# Operators from list of Hematite claimants with film badge records reviewed by SC&A
54	47	39	27	15

Source: AEC Compliance Inspection Report 1960a, p.45.

SC&A concludes that, except for Findings 1 and 2, which appear to be site profile as opposed to SEC issues, there appears to be sufficient external dosimetry data to reconstruct external doses or to develop external dose coworker models that are scientifically sound and claimant favorable.

4.2 EXTERNAL NEUTRON DOSIMETRY

Finding 3. Neutron doses assigned to UNC workers are based on bounding estimates that are not scientifically correct. The calculations potentially underestimate the doses from the scenario described by the model. However, the scenario overestimates the neutron exposure and needs to be based on assumptions that can be related to the actual operations at UNC.

According to Section 7.3.5 of the evaluation report:

> *Due to the absence of neutron monitoring data, an alternative approach for bounding neutron doses employs the methods provided in ORAUT-OTIB-0024, Estimation of Neutron Dose Rates from Alpha-Neutron Reactions in Uranium and Thorium Compounds.*

However, the evaluation report does not give any details on this approach. Such details are furnished in Appendix D (Allen 2010). The method of assigning neutron doses prescribed in Appendix D utilizes a set of bounding assumptions and is based on ORAUT-OTIB-0024 (Hysong et al. 2005). Hysong et al. (2005, Table 5.2) lists dose rates from neutrons generated by the (α,n) reaction at 1 ft and 3 ft from point sources of various compounds of natural uranium—the dose rates are tabulated as rem/h per gram of uranium. In order to estimate the neutron dose rates from enriched UF_6, Allen scaled the dose rates from natural uranium to the specific activities of 20% or 93% enriched uranium. He then multiplied by the mass in grams, assuming 100 kg of 20% or 50 kg of 93% enriched uranium. Operators are assumed to be exposed to the 20% enriched uranium source at a distance of 1 ft for 500 h/y, and to the 93% source at the same distance for an additional 500 h/y. Supervisors are assumed to be exposed to the same sources for equal amounts of time, but at a distance of 3 ft, while all other workers are assigned one-half the supervisors' dose.

SC&A (2007) has reviewed Hysong et al. (2005). We calculated the dose rates from a point source of UF_6 using the Los Alamos SOURCES4C computer code to generate the neutron spectrum and MCNP to compute the resulting doses. We found that the doses tabulated for UF_4/UF_6 by Hysong et al. (2005, Table 5.2) were 27% higher than our calculated UF_6 rates. Thus, assigning these doses to a point source of separated natural uranium in the form of UF_6 is not scientifically correct, but it is claimant favorable.

Simply scaling by the total specific activity of enriched uranium, as was done by Allen (2010), is not a valid way of estimating the dose, since the neutron emission rate is not proportional to the total alpha activity of uranium of different isotopic compositions, nor is the neutron energy spectrum constant. For example, U-234 constitutes about 49% of the total activity of natural uranium, but over 96% of the activity of 93% enriched uranium (highly enriched uranium or HEU). According to Hysong et al. (2005, Table 4-3), the neutron yield of a fluorine target subjected to alpha radiation from U-238 is ~50,900 n s^{-1} Ci^{-1}, while the yield from U-234 is ~125,000 n s^{-1} Ci^{-1}, more than twice as high. Thus, 93% enriched uranium would produce a significantly higher neutron flux, and consequently a much higher dose rate per unit activity, than natural uranium.

We next question the assumption that an operator could not be exposed to more than 50 kg of HEU due to criticality concerns. For a bare sphere of HEU in the form of pure uranium metal, the critical mass is approximately 54 kg.[2] However, the critical mass will be different for UF_6. First, the HEU metal has a density of 18.6 g/cm^3, while UF_6 has a density of 5.09 in crystalline

[2] Estimated by interpolation from Forsberg and Hopper 1998, Table 1.

form, while granulated or powdered material would have a significantly lower bulk density. Lower density would lead to a larger critical mass. Furthermore, the material would most likely not be spherical, the most compact shape which enhances criticality. On the other hand, the increased neutron emission from UF_6 might enhance criticality. In addition, fluorine, a relatively low-Z nucleus, would cause more neutrons to be thermalized, thus enhancing fission of U-235. Therefore, it is not possible to determine the critical mass of highly enriched UF_6 without performing further analyses. Since in at least one case (North 1959), the manager of the Hematite plant requested 100 kg of uranium metal, 93% enriched, in the form of UF_6, it is possible that a worker could at some time be exposed to such a quantity, unless NIOSH could demonstrate by presenting data or performing a criticality analysis on UF_6 that the quantity would be limited. We further observe that even if the HEU were stored in smaller quantities, a worker could have been exposed to more than one such source. Cylinders containing HEU were stored in racks—more than one cylinder could be placed in a single rack (AEC Compliance Inspection Report 1960a, p. 45).

Thus, for a truly bounding calculation, NIOSH should consider increasing the quantity to 100 kg HEU, and calculating the neutron dose rate from 93% enriched uranium, using the SOURCE-4C computer code to generate accurate neutron spectra and MCNP to calculate the resulting doses. It is very unlikely that a worker would receive a higher neutron dose than that calculated at a distance of 1 ft from a 100-kg 93% HEU source for 500 h/y and a 50-kg 20% enriched source for another 500 h/y.[3]

The doses presented in Appendix D are prescriptive, meaning that dose reconstructors are directed to employ them to calculate actual doses to claimants, rather than use them as bounding estimates. The distinction is important. Whereas it is appropriate for NIOSH to use bounding estimates in an efficiency process in cases where it is clear that overestimating doses will nevertheless result in a denial of compensation, bounding estimates may not be appropriate in calculating doses in cases where the decision whether or not to compensate cannot be foretold. Thus, the final consideration is the plausibility of the scenario adopted by Allen (2010). It is quite unlikely that each organ would be at a distance of 1 ft (30.5 cm) from these sources for the specified duration.

If NIOSH wishes to employ a bounding estimate in an efficiency process, the model should be revised in light of the above observations. However, NIOSH needs to develop a more realistic model to perform dose reconstructions in which a bounding model is not appropriate. For such cases, it would be advisable to interview site experts to determine the handling conditions of enriched uranium, and construct realistic scenarios. As discussed above, the SOURCES-4C code could be used to generate neutron spectra, and MCNP used to calculate the doses.

[3] North (1959) requested 50 kg of ~20% enriched uranium in the form of UF_6.

5.0 FOCUSED REVIEW OF INTERNAL DOSIMETRY DATA AND INTERNAL DOSIMETRY PROTOCOLS FOR WORKERS AT UNITED NUCLEAR CORPORATION

5.1 SUMMARY OF THE NIOSH EVALUATION REPORT FOR SEC PETITION-00116: METHODS OF MONITORING FOR INTAKE OF RADIONUCLIDES, LEVELS OF INTAKE IDENTIFIED, AND IMPLICATIONS FOR DOSE RECONSTRUCTION AS ASSESSED BY NIOSH

Beginning in 1957, UNC-Hematite plant operating personnel submitted urinalysis samples on a 3- to 6-month basis, depending on work assignments. The sampling program was based on job assignment and not designed to monitor all UNC-Hematite workers. Urinalyses generally were performed by vendors. Little information on analytical techniques is provided, other than that the focus was on exposure to U-235 and alpha radioactivity. Different analytical protocols, including "enriched" and fluorometric uranium techniques, were used, and "gross counting methods" were used. The enriched uranium techniques and gross counting methods are not described in the evaluation report. In addition, SC&A is not familiar with the term "enriched uranium techniques."

Reported urinary uranium levels occasionally included a breakdown by job categories that included operators, technicians, engineers, foremen, and guards. UNC-Hematite adopted various action levels for uranium in urine at different times. These were typically on the order of 45–50 dpm/L of urine. The maximum level recorded during the period 1957–1960 was 329.9 dpm/L. The average level was 3–5 dpm/L.

Major changes in the internal monitoring program occurred in January 1961 and December 1962:

> *The urinalysis sampling program was discontinued as of January 1, 1961. Plant management cited two primary factors: The program, in their view, had been in place for a sufficient period of time to furnish "reliable data for an overall evaluation of concentrations that may be routinely found in urinalysis samples from personnel working in the licensee's Hematite plant." Secondly, the program's cost was compared to its value "as a real and practical device for routinely measuring radiation exposure." The plant determined that bioassay services would be provided "where desirable or necessary" as required by 10 C.F.R. 20 (Compliance, 1961, pdf p. 14).* (NIOSH 2010, p. 21)
>
> *The program was re-instituted in December 1962 following operational events where several plant operators in the Red Room had higher intakes to airborne radioactive materials than expected and a higher probability of reportable overexposures during the first six months of the program. These intakes exceeded 10 C.F.R. 20 limits and were reported to AEC officials.* (NIOSH 2010, p. 21)

After its restart in December 1962, the program was continued throughout the covered operational period (i.e., through 1973). However, NIOSH considered the analytical results for the period 1971–1973 unreliable and adopted other methods for reconstructing doses for this time period.

In-vivo measurements of U-235 in the chest were made at the Y-12 plant in Oak Ridge for some UNC-Hematite workers during the years 1963, 1964, and 1965. Emphasis was on workers who had received exposures exceeding 10 CFR 20 limits, as revealed by bioassay measurements in December 1962 and early 1963. According to plant correspondence, probable causes of the high exposures included a lack of appropriate containment associated with the milling of uranium oxides and surface (hand) contamination. The workers were tracked for 3 years to confirm that U-235 levels in the body had decreased. In-vivo measurements of U-235 were made routinely during the period 1968–1973.

Measurements of removable contamination by smear samples were identified for the years 1961–1964, 1966, and 1971–1972. This information was limited to partial years. The samples were collected from equipment, floors, and other surfaces, for both clean and potentially contaminated areas.

In addition to the elevated intakes discovered in late 1962 and 1963, there were a number of other incidents resulting in elevated intake of uranium during the covered operational period. The incidents included releases of UF_6 and UO_2 in indoor work areas during 1966–1969, and various spills and releases in 1970.

Monitoring for potential intakes of thorium and chain members resulting from the project conducted in 1964 was limited to air samples. Thorium dioxide was specified as the compound of interest. Of 200-plus available air samples taken during UNC-Hematite's thorium work, more than 75% of the measured air concentrations were less than 2×10^{-11} μCi/mL, the Maximum Allowable Concentration (MAC) established by UNC-Hematite for thorium work. Approximately 10% of the recorded concentrations were more than 5 times the MAC; most of these appear to have been associated with identified events, such as spills. The maximum result for the data representing UNC-Hematite's Th-U fuel effort was 800 times the MAC and was associated with a spill. Based on the information found in the air sample data sheets, the air samples represent a combination of general area, breathing zone, lapel, stack, and hood air sample data. There is no indication that air samples were specifically analyzed for thorium isotopes.

NIOSH concluded that UNC-Hematite conducted a credible, effective radiation safety program aimed at identifying and minimizing radiation exposures to every worker:

> *It is clear from* [NIOSH's review] *that a credible radiation safety program was in effect at UNC-Hematite during 1958–1973 in conjunction with significant regulatory oversight by the Atomic Energy Commission.* (NIOSH 2010, p. 36)
>
> *Reviewed correspondence provided insights into UNC-Hematite management's commitment to evaluate each individual's internal exposures. Emphasis was placed on identifying a priori those individuals with significant potential for elevated radiation exposures, or a posteriori employing corrective measures to*

> *prevent re-occurrence. This included reassignments and job rotations employed as "ALARA-equivalent" measures to reduce unnecessary exposures…* (NIOSH 2010, p. 37)

The primary radionuclide of concern for internal exposure was uranium, except that thorium was the main concern in one area of the plant during production of thorium-uranium fuel pellets in 1964.

NIOSH also concluded that dose estimates for monitored UNC-Hematite workers for intakes of uranium during the operational period may be derived from bioassay (urine) data supported, or in some cases replaced, by air monitoring data and in-vivo measurements:

> *In summary, bioassay and air sampling data are available in sufficient quantity and quality to adequately represent internal dose for the UNC-Hematite class under evaluation over the entire operational period… Reliable routine urinalysis data are available for the entire operational period with the exception of 1961–62 and 1971–73… The available air sample data, including BZ* [breathing zone] *and GA* [general area] *data, are available and can be used to supplement the bioassay data, or as the primary source of internal monitoring data for the period from 1961–1962.* (NIOSH 2010, p. 34)

> [The available] *resources support the ability to reconstruct uranium dose using methods that are more precise than a bounding dose estimate.* (NIOSH 2010, p. 42)

For the purpose of bounding doses from internally deposited uranium associated with the weapons-related residual radioactivity remaining after the end of AEC-related operations, NIOSH intends to use the method defined in Appendix D. The method involves determining a maximum air concentration, assumed to settle and accumulate over a predetermined amount of time at the end of the operations period. NIOSH would calculate the airborne concentration for use in this method by using bounding intake rates for the UNC-Hematite operational period.

According to the evaluation report, there is no indication that air samples collected during the Th-U fuel work in 1964 were specifically analyzed for thorium isotopes. Some uranium may have also been collected on the filters. NIOSH concluded that a bounding estimate of the concentration of thorium in air can be obtained by assuming that all activity collected on the filters represents thorium deposition. The airborne concentrations determined by air sampling would be converted to personnel intake rates by applying a standard breathing rate and exposure time.

5.2 SC&A REVIEW COMMENTS

(1) The Site Profile (Allen 2010) suggests that airborne uranium will be treated as either Type M or Type S material in NIOSH dose reconstructions, generally depending on whichever gives the higher dose estimates. According to AEC inspection reports, the uranium compounds handled at this site included hexafluoride, dioxide, trioxide, diuranate, tetrafluoride, nitrate,

sulfate, and fluoride. Some of these compounds or their converted forms in air or in the lungs behave as Type F materials (ICRP 1994, Annexe F.).

Finding 4. If dose estimates are to be based in some cases on air sample data alone (an undesirable situation for a dose reconstructor), it is necessary to consider the possibility of inhalation of Type F material to avoid underestimates of doses to systemic tissues.

(2) SC&A agrees that the bioassay (urinary uranium) data provide the best available information for purposes of reconstructing doses to UNC-Hematite workers from uranium intakes. However, the sparse sampling scheme used in the bioassay program (at most four routine samples per year, depending on the job) severely limits the confidence that can be placed in the reconstructed doses for monitored workers. Such a sparse sampling scheme may fail to reveal high, short-term intakes of uranium, even for periods in which in-vivo chest measurements are also available, particularly for uranium compounds that behave as Type F material. Some UNC-Hematite workers could have had multiple short-term inhalation intakes of UF_6, say, over an extended period, that yield high doses to bone surface without ever having quarterly urinary uranium concentrations approaching the action levels used at UNC-Hematite or lung burdens detectable by in-vivo measurements. The coupling of the bioassay data with air sampling data decreases, but does not eliminate, the possibility of grossly underestimating doses to some workers from internally deposited uranium, particularly in the early years of operation when air sampling was also extremely sparse. For example, an AEC inspection report dated August 18–19, 1958, states that complete air surveys were made of the entire plant "at least twice a year," and that some sampling was done in the plant "at least one week out of every month." This is incredibly spotty air sampling that lends little support to dose reconstructions based on the sparse bioassay program.

Finding 5. Contrary to NIOSH's claim, SC&A believes it is not feasible to "reconstruct uranium dose using methods that are more precise than a bounding dose estimate" for UNC-Hematite based on the sparse routine sampling scheme used in the bioassay program, even when supported by air sampling data and in-vivo measurements. NIOSH should describe a method for deriving bounding doses based on available bioassay data for those periods for which the routine bioassay program was in place.

(3) For periods in which there was no routine bioassay program, NIOSH intends to rely on air monitoring data to reconstruct doses from radionuclide intakes due to lack or unreliability of bioassay data. A poor correlation between air monitoring data and bioassay data has been observed in a number of studies of radiation or chemical workers. Particularly poor correlations have been historically observed for static air monitoring, but breathing zone data have also been found to be unreliable predictors of bioassay data (Marshall 1976; Parker et al. 1990; Britcher and Strong 1994; Eckerman and Kerr 1999; Snapp et al. 2004; Whicker 2004; Liden and Waher 2010).

Figure 1 illustrates the poor correlation (in this case, lack of correlation) that may occur between air sampling data and bioassay data for uranium. The data are for operators in the high enrichment facility at UNC-Hematite in 1960, during a period of elevated concentrations of uranium in air in that facility (Zeitlin 1960). The air sampling value for each worker represents a time-weighted value over the 4-week period prior to urine sampling after the weekend of the fourth week.

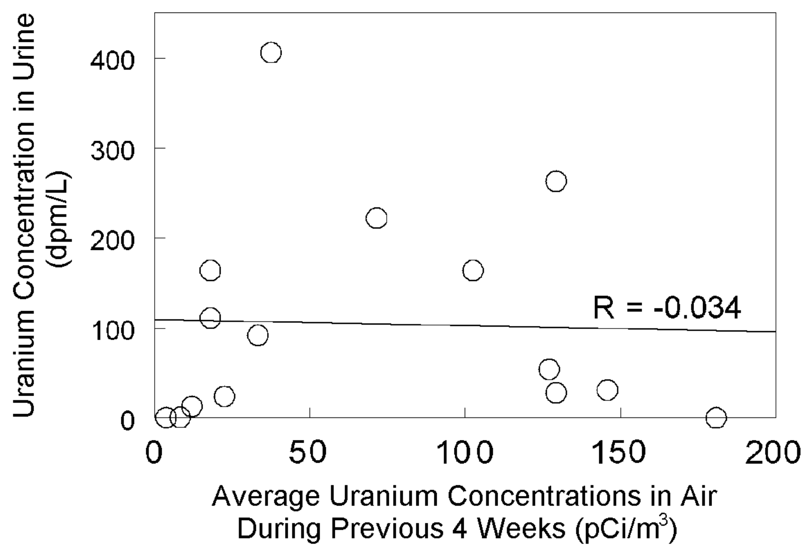

Figure 1. Relationship of Concentrations of Uranium in Air and Urine for 15 Operators in the High Enrichment Facility at UNC-Hematite in the Mid-1960s

The use of air sampling data to reconstruct doses from intakes during 1961–1962 is particularly troubling for two reasons. First, the frequency of air sampling appears to have been dramatically reduced in 1961–1962, the same period in which there was no routine bioassay program. Second, it was discovered after the reinstatement of the bioassay program in December 1962, that uranium intakes by some workers far exceeded the levels anticipated from air measurements. Although average airborne concentrations of uranium determined for each job did not exceed maximum permissible limits, concentrations of uranium in urine in a number of workers far exceeded typical levels seen in 1957–1960. Extremely high levels were found in [**redacted**] operators in the Red Room. Data for [**redacted**] of these workers is shown in Figure 2.

The following statements are from a letter dated December 23, 1963, from UNC (Kuhlma 1963) to the AEC:

> *We recognized in April of this year* [1963] that *our air sampling program was insufficient to provide proper control of exposures. A threefold increase in the frequency of air sampling was instituted.*
>
> *A systematic urinalysis program was adopted in December of 1962 as a backup to air sample data, and will be continued as a routine part of the UNC Health Physics program.*

> *Prior to discovery of the problem* [of unexpectedly high intakes] *through our Bioassay Program, average airborne concentrations determined for each job did not exceed maximum permissible limits… An intensive investigation to determine the cause of the high bio-assay results disclosed occasional local concentrations as high as* 10^{-9} *µCi/ml associated with the milling of* UO_2*.*

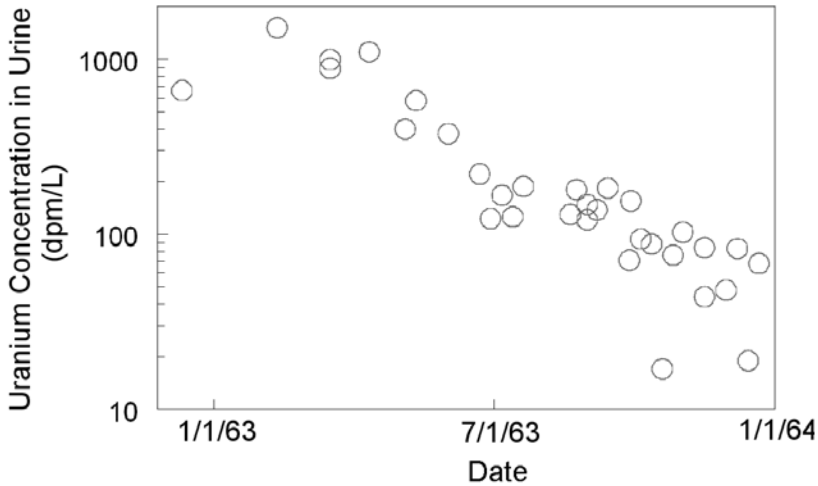

Figure 2. Urinary Uranium Concentrations in [Redacted] at UNC-Hematite, Discovered after Reinstatement of the Bioassay Program in December 1962

> *Hand contamination was found to be an additional contributor to the problem.* [This] *is believed to have resulted in the inhalation of active material transferred from the hands to cigarettes or from the hands to the air in the breathing zone of the* [**redacted**] *during rest periods off the job.*

Although the exposures of greatest concern were thought to have occurred in the Red Room, it should not be assumed that the design of the air sampling program or the adequacy of air samples as predictors of intake were any worse for this area than for other areas of the UNC-Hematite facility. In particular, there is no reason to expect that the problems of an insufficient number of air samples, local air concentrations at work stations that far exceed concentrations revealed by air samplers, and hand contamination as a source of significant inhalation and ingestion intakes were confined to a particular area of operations. Presumably, monitoring and safety procedures would not have been more lax in the high enrichment area than in other areas of the plant.

Finding 6. In view of the poor correlation between air sampling data and biological measurements frequently reported in the literature, NIOSH should demonstrate the feasibity of deriving reasonable bounding dose estimates based largely or wholly on air sampling data for the UNC-Hematitie site for the periods 1961–1962 and 1971–1973.

(4) In contrast to NIOSH's favorable review of the radiation safety program at UNC-Hematite, SC&A believes this program had serious limitations, particularly through early 1963. Examples of demonstrated or apparent inadequacies in the radiation safety program are given

below. Some of these examples repeat problems mentioned in the above comments by SC&A.

a. The air sampling program through 1958 was grossly inadequate. According to an AEC Inspection Report dated August 18–19, 1958: Complete air surveys are made of the entire plant at least twice a year and some sampling is done in the plant at least one week out of every month.

b. No full-time health physicist was assigned to the Hematite plant, at least in the first few years of operation (AEC Compliance Inspection Report 1958).

c. The routine bioassay program in place through 1960 was too limited, but nevertheless was probably the most instructive part of the radiation safety program with regard to identifying uranium intakes. The elimination of this program in 1961 is puzzling, particularly in view of uranium exposure problems that occurred in 1960 (Zeitlin 1960). UNC-Hematite management later explained the elimination of the bioassay program from 1961 through 1962 as follows: (1) The program had been in place for a sufficient period of time to furnish "reliable data for an overall evaluation of concentrations that may be routinely found in urinalysis samples from personnel working in the licensee's Hematite plant," and (2) The program's cost was compared to its value "as a real and practical device for routinely measuring radiation exposure." Part 1 of this explanation is taken by SC&A to mean that it is not necessary to continue a bioassay program at a uranium facility once typical rates of urinary excretion of uranium by workers have been established; this position is difficult to understand. Part 2 of the explanation suggests that UNC-management thought the bioassay program was too costly, in view of the fact that it was not a practical means of routinely measuring radiation exposure, which is contrary to NIOSH's conclusion that reliable dose estimates can be derived from the bioassay data collected at UNC-Hematite. In any case, the elimination of the bioassay program proved to be a major error, when it was discovered in late 1962 and early 1963 that intakes by some workers were far higher than expected on the basis of air sampling data.

d. The air sampling frequency had been greatly increased in 1959 and 1960, compared with sampling frequency in earlier years, but was greatly reduced in 1961, just as the bioassay program was eliminated. This reduction in air sampling frequency is difficult to understand and may also have been an important contributor to the lack of recognition of dramatically increased intakes sometime between January 1961 and December 1962.

e. The evaluation report suggests that UNC-Hematite discovered that elevated uranium intakes were occurring in the 1961–1962 timeframe, reported the situation to the AEC, and decided to restart the bioassay program:

> *The program was re-instituted in December 1962 following operational events where several plant operators in the Red Room had higher intakes to airborne radioactive materials than expected and a higher probability of reportable overexposures during the first six months of the program. These intakes exceeded 10 C.F.R. 20 limits and were reported to AEC officials.*

UNC-Hematite management presented a similar picture:

> *Prior to discovery of the problem* [of unexpectedly high intakes] *through our Bioassay Program, average airborne concentrations determined for each job did not exceed maximum permissible limits… An intensive investigation* [was started] *to determine the cause of the high bio-assay results* (Kuhlman 1963).

However, it appears to have been AEC inspectors and not the UNC-Hematite radiation safety program that recognized that potentially important safety issues had arisen during 1961–1962. Staff from AEC Oak Ridge Operations (ORO) inspected the UNC-Hematite facilities on August 30, 1962 (the previous AEC inspection was in early 1961). A number of non-compliance issues were identified and immediate actions were specified by the inspectors, including urinalyses for all production personnel and others thought to have had a potential exposure (Shoup and Heacker 1962). A letter from the Manager of AEC ORO to the vice president of UNC (AEC 1962) summarized findings from the inspection, including:

- Air and surface contamination and methods of operation were such that personnel may receive exposures above limits
- Existing emergency procedures were not adequate, and the responsible personnel did not have sufficient familiarity with UNC dosimetry systems to evaluate radiation exposures in the event of an emergency
- Control of contamination was generally inadequate
- Facilities and methods for storing special nuclear materials were inadequate and hazardous, in that special nuclear materials were stored in processing areas

It is apparently the result of an AEC inspection, rather than UNC-Hematite monitoring, that revealed the inadequacies of the UNC-Hematite radiation safety program and led to the reinstatement of the bioassay program, the substantial increase in air sampling, and a detailed investigation into the causes of the discrepancies in air sampling data and uranium intakes.

f. An indication that UNC-Hematite was not entirely open with the AEC concerning potential exposure problems at the site comes from a letter from the Division of Industrial Inspection, Department of Labor and Industrial Relations, State of Missouri (Cummings 1964). The letter describes problems with the plant and its management existing in 1963. The letter states, "The Atomic Energy Commission inspectors have been notifying these plants in advance of their inspections... United Nuclear Corporation has apparently been shutting down production as much as 90% during the Atomic Energy Commission inspections."

Finding 7. The radiation safety program at UNC-Hematite had serious limitations that severely hamper and possibly preclude the reconstruction of doses from intake of

radionuclides over some extended periods. The most problematic period was 1961–1962, when there was reduced air sampling and no routine bioassay program.

(5) Only a bare-bones description of the thorium program is provided in the NIOSH evaluation report. It appears that NIOSH found little information on the thorium program, judging from the repetition of essentially the same brief information in every section. The only available monitoring data for thorium and progeny are said to be air sampling data, assumed to represent ThO_2 concentrations, but apparently representing only gross alpha measurements. There is no indication that air samples were analyzed for specific thorium isotopes. All of the uncertainties associated with air sampling for uranium, described earlier, apply to thorium.

Finding 8. Considerably more information is needed before an assessment of the feasibility of reconstructing doses to thorium workers, even upper-bound doses, can be made.

6.0 SUMMARY OF FINDINGS

The results of our focused review of the SEC Petition-00116 and NIOSH evaluation report are as follows:

Finding 1. There is a need for better documentation of the beta-gamma ratios used to reconstruct external doses.

Finding 2. How were the beta gamma ratios derived and how will they be used in a claimant-favorable way for reconstructing external doses for 1961 through 1965?

Finding 3. Neutron doses assigned to UNC workers are based on bounding estimates that are not scientifically correct. The calculations potentially underestimate the doses from the scenario described by the model. However, the scenario overestimates the neutron exposure and needs to be based on assumptions that can be related to the actual operations at UNC.

Finding 4. If dose estimates are to be based in some cases on air sample data alone (an undesirable situation for a dose reconstructor), it is necessary to consider the possibility of inhalation of Type F material to avoid underestimates of doses to systemic tissues.

Finding 5**.** Contrary to NIOSH's claim, SC&A believes it is not feasible to "reconstruct uranium dose using methods that are more precise than a bounding dose estimate" for UNC-Hematite based on the sparse routine sampling scheme used in the bioassay program, even when supported by air sampling data and in-vivo measurements. Also, NIOSH should describe a method for deriving bounding doses based on available bioassay data for those periods for which the routine bioassay program was in place.

Finding 6. In view of the poor correlation between air sampling data and biological measurements frequently reported in the literature, NIOSH should demonstrate the feasibity of deriving reasonable bounding dose estimates based largely or wholly on air sampling data for the UNC-Hematitie site the periods 1961–1962 and 1971–1973.

Finding 7. The radiation safety program at UNC-Hematite had serious limitations that severely hamper and possibly preclude the reconstruction of doses from intakes of radionuclides over some extended periods. The most problematic period was 1961–1962, when there was reduced air sampling and no routine bioassay program.

Finding 8. Considerably more information is needed before an assessment of the feasibility of reconstructing doses to thorium workers, even upper-bound doses, can be made.

Before concluding, we would like to offer the following observations regarding the six petitioner concerns summarized in Section 2:

Concern #1. Transuranics are not included in the site profile for Hematite Site operations and dose reconstruction. This is a significant finding that should be considered. Indications that recycled uranium may have been brought to the Hematite Site for salvage or research were not addressed in the site profile used as the basis for dose reconstruction.

SC&A concurs with this concern.

Concern #2. The dose reconstruction protocols and the dosimetry data upon which the protocols depend, as delineated in the site profile, may not be consistent with actual occupations and task assignments at the facility, the source term (inclusive of transuranics), the extent of residual contamination, the extent of bioassay data applied to claimants, personnel protective equipment, and housekeeping practices.

SC&A concurs with this concern.

Concern #3. While there are indications that Geiger counter scans were used to monitor workers leaving contaminated areas, and that at times clothing was replaced if found to be contaminated, accepted ALARA protocols were not always implemented at the site. Specifically, the lack of adequate decontamination of personnel leaving the site could have resulted in the contamination of workers' homes, resulting in internal and external exposures of workers and their families at home. [**Redacted**].

Certainly, this concern needs to be addressed. However, it is best viewed as a subset of several of the internal dosimetry findings SC&A has identified above.

Concern #4. Internal and external dose reconstructions are challenged by petitioners' recollections of bioassay results not being shared, lack of testing, lack of annual medical exams (including blood tests), lack of confidence in personal dosimetry badge results, and both acute (incidents) and chronic (allegation of negligence) exposure to contaminants. Worker occupational category and exposure assumptions may not be consistent with claimant duties performed. For example, security guards performed laboratory technician work. Also, inadequately trained and monitored security guards responded to incidents.

Certainly, this concern needs to be addressed. However, it is best viewed as a subset of several of the internal dosimetry findings SC&A has identified above.

Concern #5. Actual conditions/incidents at the site may have a bearing on the appropriateness of site profile assumptions. For example, petitioners reported incidents with possible acute exposures and possible criticality incidents.

Our review revealed that, when incidents occurred, there were extensive bioassay investigations as a follow-up to the incidents. However, due to the hiatus on bioassays monitoring in 1961 and 1962, this concern needs to be explicitly addressed for those years.

Concern #6. The site profile should specifically address other petitioner comments and allegations. These allegations deal with falsification of data, fundamental disregard for human life, lack of quality control and dissemination of important information, and secondary exposure to contamination.

Follow-up interviews with workers regarding this concern will help to gain a better understanding of the extent to which falsification of records may have occurred. If there is evidence that records falsification might have occurred, a review of the records and data with regard to this concern is recommended.

7.0 REFERENCES

10 CFR 20. *Standards for Protection Against Radiation*, U. S. Atomic Energy Commission; Federal Register; November 17, 1960; SRDB Ref ID: 62588.

AEC Compliance Inspection Report 1958. U.S. Atomic Energy Commission. SRDB Ref ID 3822, p.14.

AEC Compliance Inspection Report 1960a. U.S. Atomic Energy Commission. SRDB Ref ID 3944, pages 46–59.

AEC Compliance Inspection Report 1960b. U.S. Atomic Energy Commission. SRDB Ref ID 7145, pages 44–58.

AEC Compliance Inspection Report 1961. U.S. Atomic Energy Commission. SRDB Ref ID 56196.

AEC 1962. Letter from the Manager of AEC ORO to the Vice President of United Nuclear Corporation summarizing inspection findings. September 5, 1962.

Allen, D. 2008. "Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium – Appendix D: United Nuclear Corp.," Battelle-TBD-6001 Appendix D, Revision No. 0. Effective Date: March 14, 2008.

Allen, D. 2010. "Site Profiles for Atomic Weapons Employers that Refined Uranium and Thorium – Appendix D: United Nuclear Corp.," Battelle-TBD-6001 Appendix D, Revision No. 1. Effective Date: April 30, 2010.

Britcher, A.R. and R. Strong 1994. "Personal air sampling – a technique for the assessment of chronic low level exposure?" *Radiat. Protect. Dosim.*, 53, 59-62, 1994.

Cummings 1964. Letter from Don L. Cummings, Director of the Division of Industrial Inspection, State of Missouri, to Senator Edward Long. February 5, 1964. SRDB 17045

Eckerman, K.F and G.D. Kerr 1999. Y12 uranium exposure study. Oak Ridge National Laboratory ORNL/TM-1999-114. Oak Ridge, Tennessee.

Forsberg, C.W., and C.M. Hopper 1998. "Definition of Weapons-Usable Uranium-233," ORNL/TM-13517. http://www.ornl.gov/sci/criticality_shielding/HopperPubs/DefWeaponsUsableU-233ORNLTM13517.pdf.

Hysong, R., W.C. Proctor, and J.J. Vollmer 2005. "Estimation of Neutron Dose Rates from Alpha-Neutron Reactions in Uranium and Thorium Compounds," ORAUT-OTIB-0024.

ICRP (International Commission on Radiological Protection) 1994. "Dose Coefficients for Intakes of Radionuclides by Workers," ICRP Publication 68. *Annals of the ICRP*, *24*(4). Tarrytown, New York: Elsevier Science, Inc.

Kuhlman, C.W. 1963. Letter from C.W. Kuhlman (United Nuclear Corporation) to the Atomic Energy Commission, dated December 23, 1963. Atomic Energy Clearing House. Volume 10 No. 3. January 20, 1964.

Liden, G. and J. Waher 2010. "Experimental Investigation of the Concept of a 'Breathing Zone' using a Mannequin Exposed to a Point Source of Inertial/Sedimenting Particles Emitted with Momentum," *Ann. Occup. Hyg.* 54:100 - 116.

Marshall, M. 1976. Air sampling in laboratories and workplaces at AERE, Harwell, Ann. Occup. Hyg., 19:153-157.

NIOSH 2010. SEC Petition Evaluation Report Petition SEC-00116. National Institute for Occupational Safety and Health, Cincinnati, Ohio. January 28, 2010.

North, E.D. 1959. Letter to Lyall Johnson, Chief, Licensing Branch, Division of Licensing & Regulation, U.S. Atomic Energy Commission, from E.D. North, Hematite Plant Manager. SRDB 3944, p.6.

Parker, R.C., R.K. Bull, D.C. Stevens, and M. Marshall 1990. "Studies of aerosol distributions in a small laboratory containing a heated phantom." Ann. Occup. Hyg. 34:35-44.

SC&A 2007. "Task 3: Review of NIOSH/ORAUT Procedures and Methods Used For Dose Reconstruction (Supplement 1)," SCA-TR-TASK3-0001, Rev. 1, SC&A, Inc.: Vienna, Virginia. August 2007.

SC&A 2009. *Review of the NIOSH Site Profile for the United Nuclear Corporation, Missouri, Battelle-TBD-6001, Appendix D*. SC-TR-SP2009-0004, Revision 0. SC&A, Inc.: Vienna, Virginia. September 10, 2009.

SC&A 2010. *A Critical Review of Revision 1 the NIOSH Site Profile for the United Nuclear Corporation, Missouri, Addendum to SCA-TR-SP2009-0004*. SCA-TR-SP2010-0004-ADD. SC&A, Inc.: Vienna, Virginia. June 17, 2010.

Shoup, C.S. and H.V. Heacker 1962. Letter from C.S. Shoup and H.V. Heacker (AEC ORO) to United Nuclear Corporation. Lists a number of non-compliance issues identified and immediate actions specified by inspectors. September 4, 1962.

Snapp, L.A., M.L. Souleyrette, and K.G. Veinot 2004. "Practical use of personal air sampling (PAS) data in the internal dosimetry program at the Y-12 National Security Complex." Midyear Health Physics Society Meeting, pp. 78–86.

Whicker, J.L. 2004. "Relationship of air sampling measurements to internal dose: a review." Midyear Health Physics Society Meeting, pp. 73–77.

Zeitlin, F. 1960. Letter from F. Zeitlin (Mallinckrodt Chemical Works, Nuclear Division) to H.L. Price (AEC, Director, Division of Licensing & Regulation). December 16, 1960. SRDB 17606.

ATTACHMENT A: DETAILED SUMMARY OF THE SEC-00116 PETITION ISSUES

Attachment A (pages 35–38 of the original document) was redacted in its entirety for Privacy Act protection.

ATTACHMENT B: UNITED NUCLEAR CORPORATION EEOICPA CLAIMANTS

Attachment B (pages 39–42 of the original document) was redacted in its entirety for Privacy Act protection.

ATTACHMENT C: INDIVIDUAL FILM BADGE RESULTS FOR UNITED NUCLEAR CORP. PERSONNEL

Attachment C (pages 43–91 of the original document) was redacted in its entirety for Privacy Act protection.